Surface Degradation and Mechanical Properties of PVC/Wood-Pallet Composite under UV-Weathering Environment

B. Sreenual[1, a], D. Atong[2, b] and C. Pechyen[1, 3, c]

[1]Department of Packaging and Materials Technology, Faculty of Argo-Industry, Kasetsart University, Bangkok 10900, Thailand

[2]National Metal and Materials Technology Center, 114 Thailand Science Park, Pathumthani 12120, Thailand

[3]Center for Advanced Studies in Agriculture and Food, KU Institute for Advanced Studies, Kasetsart University, Bangkok 10900, Thailand (CASAF, NUR-KU, Thailand)

[a]bandit.sn@hotmail.com, [b]duangdua@mtec.or.th, [c]chiravoot.p@ku.ac.th

Keywords: Polyvinylchloride, Wood Composite, UV-Weathering, Degradation

Abstract. This research studied the effects of 4 types of additives, , wood powder, UV-absorber, impact modifier and pigment, on UV- stability of PVC/Wood-Pallet prepared by extrusion process. The amount of additive used was varied from 0 – 35 %w/w. The central composite design (CDD) was employed to experimentally design the formulation of PVC/Wood-Pallet, in order to practically reduce the total number of experiments from 625 pipes (Full factorial design for 4 factors and 5 levels) to 30 pipes without losing the credibility of the results achieved. The photodegradation of the PVC/Wood-Pallet was performed by an outdoor exposure test. The progress of photodegradation was followed by determining the changes in mechanical properties, physical properties and appearance, and thermal properties as a function of exposure time. The results showed that the PVC/Wood-Pallet No.30 had better mechanical properties than the others over period of exposure time. In addition, it was found that UV exposure could actually improve short-term mechanical properties due to postcuring phenomenon.

Introduction

Wood-plastic composites (WPCs) are composite materials made of wood fiber/flour and plastic. In addition to wood fiber and plastic, WPCs can also contain other ligno-cellulosic and/or inorganic filler materials. WPCs can also be referred to as natural fiber plastic composites or natural fiber reinforced plastics. The most widespread use of WPCs is in outdoor deck floors, but it is also used for railings, fences, landscaping timbers, cladding and siding, park benches, molding and trim, window and door frames. Wood-plastic composite is still a very new material relative to the long history of natural lumber as a building material, but can be substituted in most non-structural instances. A major advantage over wood is the ability of the material to be molded to meet almost any desired spatial conditions. It can also be bent and fixed to form strong arching curves. With up to 70 percent cellulose content (although 50/50 is more common), wood-plastic composites behave like wood and can be shaped using conventional woodworking tools. At the same time, they are moisture-resistant and resistant to rot, although they are not as rigid as wood and may slightly deform in extremely hot weather. Wood-plastic composite lumber is composed of wood from recovered saw dust (and other cellulose-based fiber fillers such as pulp fibers, peanut hulls, bamboo, straw, etc.) and virgin or waste plastics including high-density polyethylene, PP, ABS, PS and PVC. Polyvinyl chloride, commonly abbreviated PVC, is a thermoplastic polymer. A number of

PVC's properties recommend it for a wide variety of applications. It is biologically and chemically resistant. With the addition of impact modifiers and stabilizers, it becomes a popular material for window, door frames and pallet application. Additives such as colorants, coupling agents, stabilizers, blowing agents, reinforcing agents, foaming agents, lubricants help tailor the end product to the target area of application. In this paper, the mechanical and surface performance of PVC/Wood-Pallet have been studied at different time, and the effects of outdoor exposure time on the surface morphology and mechanical properties have been investigated in detail.

Experimental Procedure

Apart from main compositions, the additives also affected the properties of PVC/Wood-Pallet. In this work, the effect of the type and amount of various additives on the physical and mechanical properties of FRP were investigated. These investigated factors were the amount of wood powder, UV-absorber, impact modifier and pigment. Each factor was evaluated at five different levels. The five levels for each of the four factors are shown in Table 1.

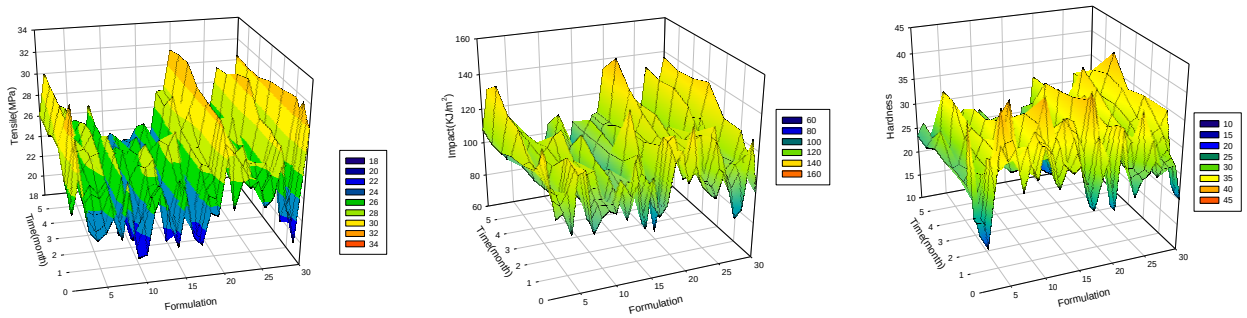
Table 1 Factors and Investigated levels

Factors	Coded Levels				
	-2	-1	0	1	2
Amount of Wood powder	15.00%	20.00%	25.00%	30.00%	35.00%
Amount of UV-absorber	0.00%	0.50%	1.00%	5.00%	10.00%
Amount of Impact Modifier	1.00%	3.00%	5.00%	7.00%	10.00%
Amount of Pigment	0.10%	0.30%	0.50%	0.70%	1.00%

If a full factorial experiment were to be performed, the total test runs would be 5 x 5 x 5x 5 = 625 runs, which was considered too large of a test matrix for practical considerations.To practically reduce the total number of experiments without losing credibility of the results obtained, the central composite design (CCD) employed. The CCD is feasible to run 5 levels of each factor. The total number of test runs (n) in a CCD based on a complete 2^k factorial is $n = 2^k + 2k + m$. The number of experimental runs required for the four-factor CCD with five levels of each factor are 30 (not show here). PVC/Wood-Pallet were first constructed from the mixture of PVC and plasticizer with the addition of four aforementioned additives including wood powder, UV-absorber, impact modifier and pigment. PVC/Wood-Pallet are fabricated by extrusion technique where a band of continuous process. People (Thailand) Co., Ltd. variety of die type and different length of sample are varied upon specification required. The composite material was extruded in a twin-screw extruder (ZSK-25WLE, WP, Germany, the temperatures for the processing sections are 165°C, 165°C, 165°C, 170°C, 170°C, 195°C, 195°C, 195°C; twin-screw rotation speed: 180 r/min). Outdoor exposure of PVC/Wood-Pallet was carried out in Nakornpratom, Thailand for 6 months. The mechanical and surface properties of PVC/Wood-Pallet samples were tested at 0 day, 1 week, 2 week, 3 week, 1 month, and every 1 month of an exposure until 6 months. Tensile testing was carried out at the ambient temperature according to the ASTM D 638 specifications on the Universal Testing Machine, model LLOYD LR 100K. Izod-impact testing was performed flowed the ASTM D256. Hardness of rigid plastics was carried out by means of a Barcol impressor in accordance with the ASTM D2583-95. A scanning electron microscope (SEM) can be used to examine the morphology or surface irregular of fracture areas in a part and also to measure the thickness (in cross section) of coating.

Results and Discussion

Mechanical Properties. Fig.1(a) shows the effects of exposure time on the tensile strength of all PVC/Wood-Pallet under outdoor exposure The PVC/Wood-Pallet were exposed to natural UV radiation via outdoor exposure in Nakornpratom Province for 6 month. The tensile tests were carried out on the samples prior to and following exposures at every 7, 14, 21 days and 1, 2, 3, 4, 5, 6 months. From this figure, if was shown that negligible changes in tensile strength were observed for the PVC/Wood-Pallet No.2, 20, 27 and 30 compared to the others following the 6-months outdoor exposure. To clarify these results, Figure Fig.1(a) presents the tensile strength of PVC/Wood-Pallet before and after exposed to sunlight and Q-UV for 6 months. Obviously, the tensile strength of the PVC/Wood-Pallet before photodegradation test are fallen within the range of 20 – 30 MPa, depending on the types and amount of additives used in each formula. The impact strength values of PVC/Wood-Pallet in an outdoor exposure tests are shown in Fig. 1(b). Similar to the tensile properties, it may be observed that the PVC/Wood-Pallet No.2, 20, 27 and 30 generally had greater impact strength than the others. The effect of outdoor exposure test on the hardness of all PVC/Wood-Pallet can be observed in Fig. 1(c). From Fig. 1(c), similar to tensile and impact properties, the post curing reaction during the first year of exposure can be observed. The decrease in hardness of PVC/Wood-Pallet after longer exposure time, especially the PVC/Wood-Pallet No.9, is due to the microstructural chages by photodegradation, in particular at the surface, and appear as the micro-crack around the surface of epoxy matrix, as evidenced by SEM analysis. The degradation can be minimized by adding suitable types and amount of additives. The greater in hardness values of the pipes No.20 and 30 may be owing to the higher amount of additives. Beside the amount of additive, since the hardness is the surface property rather than bulk property of the materials. Powder of additives which were orderly dispersed on the surface should increase in hardness, where as the agglomerate powder of additives results in decrease in hardness.



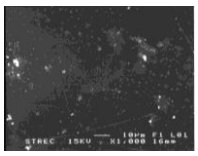
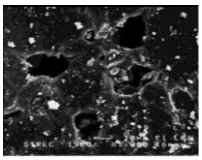
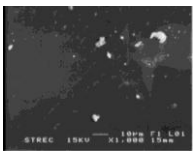
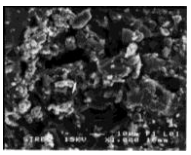
(a) (b) (c)

Fig. 1 Mechanical properties of PVC/Wood-Pallet : (a) tensile strength, (b) impact strength and (c) hardness after 6 months of outdoor exposure

Surface Morphology. The effects of UV exposure, or photodegradation, are usually confined to the top few microns of the surface. In other words, UV damage is a surface phenomenon. Changes in surface morphology of PVC/Wood-Pallet as a function of exposure time under outdoor tests were examined by scanning electron microscopy (SEM), as shown in Table 2. As shown, before degradation test the surfaces of PVC/Wood-Pallet were shown to be smooth and homogeneous. However, after 6 months of outdoor exposure, surface morphological changes were evident. PVC/Wood-Pallet and / or additives, loss were observed in the form of cratering and cracking and the size and amount of these surface degradation was notice ably increased as a function of exposure time. Particularly, the surface erosion was more pronounced for the PVC/Wood-Pallet No.9, as presented in Table 2., which contained less amount of UV-absorber and impact modifier. The surface photodegradation induced by UV can serve as stress concentrators to initiate crack growth and subsequent damage. Obviously as presented in every SEM micrographs

for exposed specimens, the damage region or so called “reaction zone” is established by the photo-oxidation reactions occurring near surface regions. As materials in the reaction zone is volatilized or washed away, new surface is exposed which then undergoes the same photochemical reactions to re-establish the reaction zone. Therefore, upon increasing exposure time to sunlight or Q-UV, the degree of surface degradation was found to be significantly increased. And as expected and discuss earlier, this surface erosion eventually leads to changes in mechanical and physical properties after long exposures. However, for mechanical properties, degradation at the surface can not affect mechanical properties during the first year of exposure. In contrast, UV exposure could in fact improve mechanical strength due to post curing phenomenon, but eventually matrix degradation occurred beyond 1 year of exposure which led to decrease in mechanical properties.

Table 2 Effect of outdoor exposure time test on formulation No.30 vs No.9 PVC/Wood-Pallet measured after ageing for 0 day to 6 month

Formula	No.30		No.9	
Time	0 month	6 month	0 month	6 month
X 1000 (manification)				

However, the rate of photo-oxidation reactions can be minimized by the use of certain type of additives. These results suggest that there was no conclusive answer to which condition is more aggressive. In fact, results of testing in outdoor environments are seldom reproducible, due to highly variable nature of the weather and associated climatic factors. They are influenced by fluctuation in temperature, moisture, and UV irradiation. The intensity of UV irradiation changes with test location, the season in which the testing is performed, and year to year fluctuations.

Conclusions

The PVC/Wood-Pallet No.30 had better mechanical properties than the others over period of exposure time. Similar results were observed in outdoor tests. In addition, it was found that UV exposure could actually improve short-term mechanical properties due to postcuring phenomenon. Under the accelerated condition (data not show here), it was found that upon increasing the Q-UV exposure time, the physical properties in terms of the density, color, and gloss were decreased. Color changes involved initial fading followed by subsequent increased level of yellowing. The decrease in density and gloss values were attributed to the surface degradation induced by UV-irradiation.

Acknowledgements

This study is financially supported by NSTDA-University-Industry Research Collaboration (NUI-RC-M33-11-54-008M) and National Research Council of Thailand.

References

[1] X.Wang, Y.Guo, J. Liu, Q. Qiao, J. Liang: Journal of Environmental Management Vol.91, (2010), p.2505-2510